Available online at www.sciencedirect.com

ScienceDirect

Renewable and Sustainable Energy Reviews
12 (2008) 807–823

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

www.elsevier.com/locate/rser

Prospects for solar water heating within Turkish textile industry

T. Muneer[a,*], M. Asif[a], Z. Cizmecioglu[b], H.K. Ozturk[c]

[a] *Napier University, Edinburgh, UK*
[b] *Yildiz Technical University, Istanbul, Turkey*
[c] *Pamukkale University, Denizili, Turkey*

Received 12 October 2006; accepted 13 October 2006

Abstract

Turkey is a free market economy that is oriented towards Western markets. It also has strong ambitions to join the European Union and this factor has been beneficial as well taxing with respect to its changing economic situation. In terms of world textile strand production, on a production per capita basis, Turkey occupies the third place in the world. Thus, the economic importance of textile industry for Turkey and its need for consolidation within the world markets is essential. Turkey imports nearly 50% of its energy requirements. The country spends 40–50% of its total export income to import fuel, mainly crude oil and natural gas. The aim of this study is to investigate the possibility of exploitation of solar energy within the Turkish textile industry with particular reference to thermal application and critically examine the present opportunities and barriers. A discussion on the possible adoption of instruments that will help alleviate the barriers is also presented. Results of a detailed life cycle assessment and relevant economics of solar water heater have also been presented. As an addendum the potential for solar water heating within the domestic sector is also briefly discussed.

Keywords: Solar water heating; Sustainable energy systems; Energy budget for Turkey; Renewable energy

*Corresponding author. Tel.: +44 131 455 2541; fax: +44 131 455 2264.
E-mail address: t.muneer@napier.ac.uk (T. Muneer).

1364-0321/$ - see front matter
doi:10.1016/j.rser.2006.10.024

Contents

1. Introduction

Turkey is made up of a European part, Eastern Thrace, and an Asiatic part, the Peninsula of Anatolia, separated by the Dardanelles, the Sea of Marmara and the Bosphorous. Eastern Thrace located in the southeast of the Balkan Peninsula, makes up less than one-thirtieth of the country's total land area. Anatolia is a mountainous area with many lakes and wetlands. The Ponticas range in the north and the Taurus range in the south form the natural boundaries for the Anatolian Plateau, which extends eastward to form the Armenian plateaus [1].

Turkey is one of the largest economies within the Balkan region achieving an average annual growth rate of 4.1% over the past 25 years and a Gross National Product (GNP) that totaled \$204 billion in 1998, increased to \$363 billion in 2005 and is expected to reach

up to $414 billion by the end of 2006. Strong population growth and rapid urbanization have played an important role for development of Turkey. In the period 1980–2005, Turkey's export figures showed an average annual increase of 33%. In 2005, Turkish exports reached US $72.4 billion as shown in Fig. 1 [2].

Turkey is a free market economy that is oriented towards Western markets. It also has strong ambitions to join the European Union (EU) and this factor has been beneficial as well taxing with respect to its changing economic situation. In Sections 2 and 3 of this article the latter factors shall be discussed in further detail. In 2005, the OECD countries took a 68% share in the total exports of Turkey with a value of US $18.7 billion. Among OECD members, exports to the EU were US $14.4 billion a figure that is equal to 52.5% of total exports [3]. Tables 1 and 2, respectively, provide details of Turkey's major markets and its export growth profile [4].

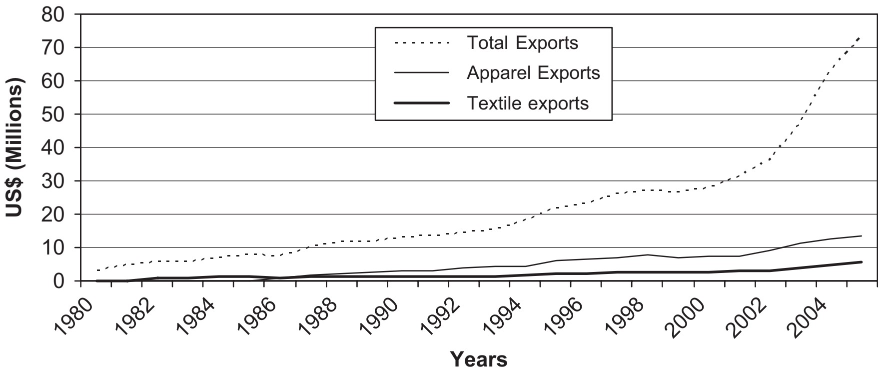

Fig. 1. Textile, apparel and total exports of Turkey.

Table 1
Turkey's world exports and imports shares of EU countries (%) in textile and clothing, 2002

Countries	Exports	Imports
Germany	26.6	9.3
The United Kingdom	13.8	3.9
France	7.0	5.2
Italy	4.1	17.2
The Netherlands	4.6	1.5
Total for EU	66.8	48.9

Table 2
Export profile for Turkey (US$ billions)

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Export	18,106	21,636	23,225	26,261	26,973	26,587	27,775	31,340	36,100	47,300	63,100	72,400

Table 3
World textile strand production (million tonnes), column A and production per capita, column B (year = 2005)

	A	B (kg/capita)
China	22.8	17
USA	3.7	12
Taiwan	2.4	104
South Korea	2.0	41
India	4.6	4
Pakistan	2.5	15
EU	1.9	4
Turkey	1.8	26
Brazil	1.2	6
World	56.6	9

Table 4
Export profile for Turkish textile industry for the year 2005 (million USD)

	Textile loom	Garments	Leather	Carpet
Exports	2752	10,309	825	205

Tables 3 and 4, respectively, provide information on the world textile strand production, production per capita and the export profile for Turkish textile industry for years 2004–05 [4,5]. These tables clearly demonstrate the economic importance of textile industry for Turkey and its need for consolidation within the world markets.

The energy requirement for an economy is obviously sensitive to the rate of economic growth and the energy intensity of producing sectors. The energy intensity of industry is a function of technological progress and varies from sector to sector. Turkish domestic energy resources are highly utilized, albeit significantly short of being sustainable and the economy is dependent on imports particularly of petroleum products. Turkey imports nearly 50% of its energy requirements. The country spends 40–50% of its total export income to import fuel, mainly crude oil and natural gas. Oil and natural gas meet nearly 60% of energy demand in the country, with coal constituting nearly 25% of supply [2]. The Turkish industry is one of the significant consumers and hence it is vital for it to improve the efficient use of energy.

The aim of this study is to investigate the possibility of exploitation of solar energy within the Turkish textile industry with particular reference to thermal application and critically examine the present opportunities and barriers. A discussion on the possible adoption of instruments that will help alleviate the barriers is also presented. As an addendum the potential for solar water heating within the domestic sector is also briefly discussed.

2. A profile of Turkish textile industry

The GNP of Turkey decreased from about US $192 billion in 1997 to US $148 billion in 2001 due to the general economic crisis (see Table 5). After 2001 crisis, Turkish economy showed rapid recovery and GNP increased to US $359 billion in 2005 [4].

Table 5
GNP and GNP per capita of Turkey (producers value at 1987 prices) [X3]

Year	1990	1997	1998	1999	2000	2001	2002	2003	2004	2005
GNP ($ billion)	152.4	192.4	206.6	185.2	200.0	148.2	180.9	270.3	302.8	359.1
GNP per capita ($)	2698	3079	3255	2879	2965	2160	2598	3383	4256	4982

In 2004, Turkey's GDP was over $300 billion, making it the world's 20th largest economy. With its performance in 2005, Turkey has become the 22nd largest exporter and 14th largest importer country and recorded one of the highest export growth rates in the world. Exports in 2005 amounted to US $72.4 billion, breaking all records in the history of the country [6].

The textile industry is the largest and one of the first established industries in Turkey. However, clothing industry began in the 1950s and at the beginning, served only the domestic consumption, and therefore its development remained limited until the end of the 1970s. Today, textiles and clothing industry is an outward oriented industry, mostly using modern technology, and can compete with that of other countries in international markets. The textile and clothing sector in Turkey accounts for 11–12% of GNP, one-third of exports, and 10% of industrial output by value. Turkey is among the world's top 10 textile exporters with 49,000 small and medium enterprises active within this sector.

The value of textiles and clothing industry production was around $27.7 billion in 2002 and exported 44% of that amount. Its share in manufacturing production in 2002 was 1.5%. Textile and apparel exports were 18.6 billion USD in 2005, representing 26% of Turkey's total exports. Around 42% of the total textile and wearing apparel exports go to EU 25 countries. Germany, UK, France and Holland are the main importers of Turkish apparel accounting for 54% of all Turkish apparel exports. The US accounts for another 14% of Turkish exports [7].

2.1. The energy budget

The following energy and econometric data for the year 2005 will enable an assessment that pertain to the present study: Energy consumption of 1144 kg of oil equivalent per capita annually (15,120 kWh/capita annum), around 50% of which is imported, per capita GDP of $6974, an annual growth rate of 5.7%, annual inflation of 54%, exports $72.4 billion, imports $63 billion and bank interest rates averaging between 22–24% [1].

Table 6 provides further energy and economic information for Turkey and places it in contrast to the relevant data for the EU and the world. Table 7 and Figs. 2 and 3 provide details of the energy consumption trends and fuel mix for Turkey [5,8].

2.2. The cost of energy within textile and domestic sectors

The year 2006 energy cost data for Turkey is provided in Table 8. It is apparent from these statistics and the information provided above that Turkey is heavily dependent on imported energy and as such its cost per unit of goods produced and also as compared to GDP/capita is considerably higher than its opulent neighbour, i.e. the EU.

Table 6
Energy and economic profile for Turkey

Present energy supply matrix for Turkey	Hydro (23%), gas (43%), coal (30%), others (4%)
Proven hydropower potential	126 million kWh
Exploited potential	35%
Turkish per capita energy consumption	15120 kWh/annum
EU per capita energy consumption	47440 kWh/annum
World per capita energy consumption	19460 kWh/annum
Turkish yearly increase of energy consumption	8%
Turkish per capita electricity consumption	2000 kWh/annum
EU per capita electricity consumption	5930 kWh/annum
World per capita electricity consumption	2367 kWh/annum
Turkish yearly increase of electricity consumption	6%
2005 annual electricity consumption	160 million kWh
2005 peak electric power requirements	25.1 GW
Electricity price for Turkish industry	6.7 US cent/kWh
Electricity price for OECD	6 US cent/kWh

Table 7
Energy consumption trend for Turkey

Year	Peak electrical power consumption (GW)	Energy consumption (TW h)
1995	14.2	86
1996	15.2	95
1997	17.0	106
1998	17.8	114
1999	18.9	118
2000	19.4	128
2001	19.6	127
2002	21.0	132
2003	21.7	141
2004	23.2	149
2005	25.1	160

2.3. Solar energy availability

The Turkish State Meteorological Service has the responsibility of producing measured solar radiation data for the state of Turkey. The observations mainly consist of sunshine duration measured via sunshine recorder and global solar radiation data obtained from actinographs. The latter datasets are available, respectively, for a network of 192 and 163 stations spread all over the country. However, an assessment undertaken by the aforementioned Meteorological Service [9] showed that the actinograph data obtained from those instruments were not reliable due to the thermal sensitivity of the mechanical components of the sensors. For example in the last-mentioned study it was found that when global solar radiation data obtained from actinographs were compared with data obtained from pyrheliometers the observed actinograph data showed a high error rate with respective differences of 14.7% for annual and 42.1% for monthly averages.

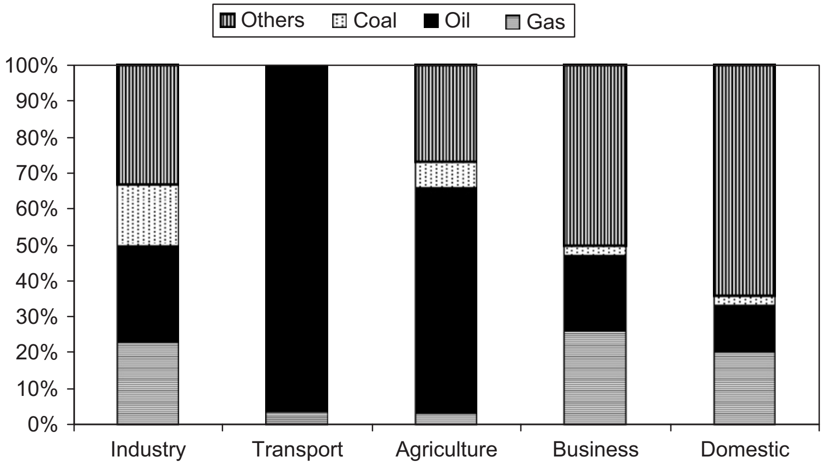

Fig. 2. Sectorial fuel mix for Turkey (2005).

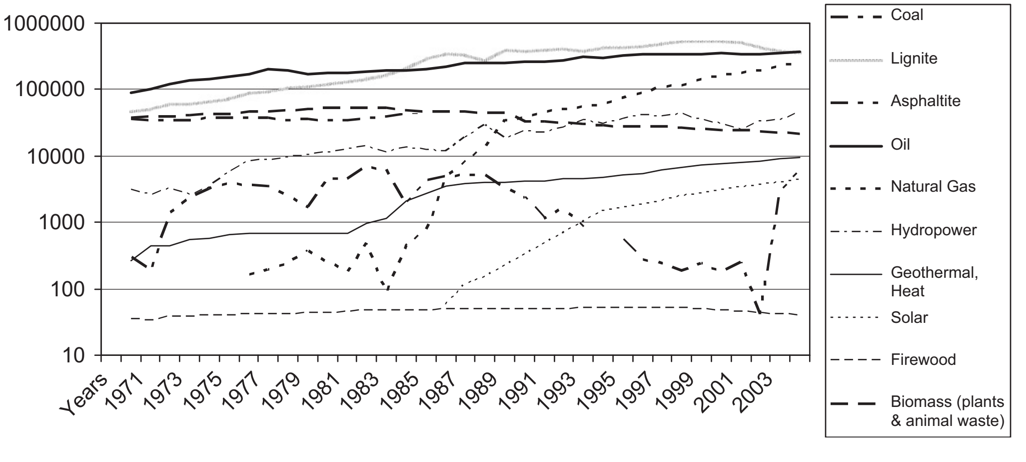

Fig. 3. Energy supply trend for Turkey.

Table 8
Energy cost data for Turkey, July 2006

	Domestic sector	Industrial sector
Gas (US cents/kWh)	3.0	2.5
Petroleum (US cents/litre)	185.6	185.6
Electricity (US cents/kWh)	11.3	6.7

To overcome the shortcoming of acquiring a reliable dataset using the above-mentioned historical records of actinograph-based measurements, the Turkish State Meteorological Service has used recently recorded, more reliable pyrheliometer-based data. Hence data

Table 9
Monthly-averaged daily solar radiation and ambient temperature (T_{max} & T_{min}, °C) data for Turkey

Month	Ankara (MJ/m^2)	Konya (MJ/m^2)	Samsun (MJ/m^2)	Urfa (MJ/m^2)	Antalya (MJ/m^2)	T_{max} of Antalya (°C)	T_{min} of Antalya (°C)
1	6.07	7.58	4.87	6.46	7.80	14	6
2	8.01	10.01	6.59	10.74	11.59	15	6
3	13.45	14.59	10.95	15.77	15.10	18	8
4	19.29	20.63	16.06	20.48	19.04	21	11
5	21.87	24.74	18.82	23.97	24.11	25	14
6	26.92	28.63	24.10	28.55	26.46	30	19
7	25.56	27.24	24.22	26.82	25.41	33	22
8	23.12	24.25	19.77	25.42	24.02	33	22
9	18.77	20.53	16.83	17.83	19.80	31	19
10	11.30	13.10	10.10	12.99	11.67	26	14
11	6.67	7.99	4.81	7.50	8.88	21	11
12	3.94	6.40	4.76	4.71	7.16	16	7

from five stations, i.e. Ankara, Antalya, Konya, Samsun and Urfa, with measurements undertaken from 1993 onwards were employed to produce regressions for estimating irradiation from longer-term records of sunshine.

The final regression that was developed from the pyrheliometer-based data produced an R^2 of 0.94. It was shown that monthly average global radiation was obtainable with a 3.8% maximum deviation from the mean error. Table 9 displays estimates of global solar radiation data for Turkey that were obtained using the above modeling procedure.

3. Present opportunities and barriers for the introduction of sustainable energy technologies within Turkey

3.1. Opportunities

3.1.1. Healthy solar energy income

Refer to Table 9, the mean annual daily irradiation for the five Turkish locations are, respectively, 4.278, 4.750, 3.750, 4.667 and 4.667 kWh/m^2 with a national average of 4.422 kWh/m^2. These energy incomes are now compared with the corresponding figures for Germany, Turkey's northern neighbour. If one takes data for the representative locations within Germany such as Hamburg (53.6°N), Hanover (53.6°N), Berlin (53.6°N), Gelsenkirchen (53.6°N), Frankfurt (53.6°N) and Freiburg (53.6°N) one notes that the respective corresponding irradiation are 2.649, 2.680, 2.682, 2.539, 2.803 and 3.043 kWh/m^2 [10]. The national average for Germany is thus 2.733 kWh/m^2. We note here with interest that although the annual average solar energy income for Germany is only 62% of the corresponding figure for Turkey, the uptake of solar water heating is much more so in Germany, i.e. during the year 2004 the ratio of solar collector energy output per capita by the German manufacturers to that of their Turkish counterparts was 1.56. It must be further noted that most of the Turkish deployment of solar water heating technology is only within the hotel and recreation industry along the southern coast.

3.1.2. Local, hi-tech solar water heating industry

A recent survey of globally leading solar water heating manufacturers was undertaken by Sun and Wind Energy [11]. That survey showed that amongst the top 25 world manufacturers, Turkey hosts four such manufacturers. Hence, there is no shortage of technical knowhow with regards to large scale manufacture of solar water heating and exploitation of solar energy. Unfortunately, there has been little market penetration of solar water heating sales within the domestic and industrial sectors, with the local production either being used within the hotel industry serving the southern coast or exports to EU.

3.1.3. Well trained task force

Owing to its unique position within Europe, Turkey has always been a strategic partner within NATO and this has resulted in a fairly decent network of universities and technical colleges. Furthermore, owing to its close proximity to Germany and a constant flow of the Turkish population to-and-fro to the latter country, a well trained task force is available for employment. Turkey has made valuable economic gains within building construction trade and it may therefore be opportune for it to turn its attention now towards sustainable energy sector.

3.1.4. Aspiration to join the EU and signatory to the Kyoto protocol

Turkey's aspiration to join the EU provided a powerful incentive for reform, but in the first two years, progress was slow, characterized by superficial half measures that brought about little fundamental change. In a potentially significant turnaround, however, the EU accession process has over the past year begun to reap real results in the human rights situation, though important tasks remain. If Turkey is accepted within the folds of the EU then its export potential is further improved and this may lead to a further demand for energy. Furthermore, the EU directives would require Turkey to produce its energy in a more environmentally sustainable manner and this would thus be a further opportunity for introduction of solar water heating.

3.1.5. Rising labour costs within all manufacturing sectors

Owing to the fact that Turkey has been very vigorous in its attempts to join the EU, the labour laws have seen a rapid convergence towards the West European practice. Hence, the payment for an 8-h shift labour increased from an average figure of $300/month in the year 2000 to $450/month in 2004 and then to $800/month in 2006. As a consequence labour cost within the textile sector now represents the highest single slice (35%) of the total. The energy cost is the next highest category with a 28% share of the total. The remainder of the costs are incurred in the purchase of materials and administration. Therefore, there exists a good opportunity for reducing the energy bill via use of solar energy to compensate for rising labour costs.

3.1.6. A high, near constant load demand of hot water that is needed throughout the year by industry thus making solar energy economically viable

Fabric production involves numerous stages of scouring, bleaching, dyeing, washing, oiling and drying. In most Turkish factories the hot water that is required for the above stages of production must be available at 40, 60 and 80 °C. One of the dyeing processes that needs water at around 60 °C requires a very close control of temperature increment. A stepped increase rate of 1 °C/min to raise water temperature from 55 to 65 °C is thus

required. In the present study this stream of thermal energy requirement has not been taken on board. Thus, the proposed design is only for supply of hot water at 40 and 80 °C. Most textile industries in Turkey operate on a 24-h shift with a constant demand for hot water and this is therefore an additional opportunity for introduction of solar heated hot water. In the current simulation software it was thus assumed that for each of the hours of 1100–1600, 15% of the heated water is drawn from the storage tank. At 1700 h hot water from the tank is then completely discharged and used up within the textile mill.

3.1.7. Major price changes in gas supply from Russia that are inducements for investment in solar energy

Natural gas production in Europe is declining while demand will grow over the foreseeable future. IEA has determined that imports will thus grow from 35% of demand in 2004 to 65% of demand by 2030. Within the member states of EU-25 the expected growth in energy demand will reach over 80% by 2030 [12]. With gas being sourced predominantly from Russia with the latter providing 25% of OECD European consumption, countries such as Turkey would be well advised to switch to a more sustainable energy source such as solar thermal.

3.1.8. Overall increase in energy prices and security of energy supply

The rise in energy prices has been making headlines across the globe over the last few years. Increasing demand especially from countries like China and India, geopolitical features across the world especially in Middle Eastern region and weather related supply shocks have fuelled the continual rise in crude oil prices. The cost of crude oil, which was 17 USD barrel at the end of 1999, had reached 35 USD/barrel by the end of 2004. Oil prices have especially skyrocketed after July 2005 for various reasons. By the middle of 2006 the price stands well over 60 USD/barrel.

The economies of all countries are dependent on secure supplies of energy. Energy security means consistent availability of sufficient energy in various forms at affordable prices. These conditions must prevail over the long term if energy is to contribute to sustainable development. Attention to energy security is critical because of the uneven distribution of the fossil fuel resources on which most countries currently rely. Energy supply could become more vulnerable over the near term due to the growing global reliance on imported oil. With about 6% of the world's population, the EU is responsible for some 14–15% of global energy consumption. By 2030 the proportion of energy import for the EU will reach 70% and although energy security has been adequate for the past 20 years, the potential for conflict, sabotage, disruption of trade, and reduction in strategic reserves cannot be dismissed. These potential threats point to the necessity of strengthening global as well as regional and national energy security [13].

3.1.9. Introduction of carbon tax

For the past several years tradable carbon permit schemes have been in operation throughout the EU. However, a good proposition of shifting that policy from permits to taxes has been introduced by Nordhaus [14]. Under the latter scheme, countries would impose a common tax on carbon emissions, but would keep the revenue. Rich countries would transfer the technologies for emission reduction at a subsidised price. Poor countries would have lower taxes and the poorest none. Under this type of scheme the cost of emissions would be known and fairly uniform, instead of volatile. Wolf [15] has reported an

average figure of 170 USD/tonne of carbon that would generate USD 1.2 trillion worldwide and this is equal to 3% of the global GDP. Working along similar lines, the present authors have worked out the 'optimal carbon tax rate' that would provide an instrument for the introduction of solar water heating within the domestic and textile sectors. The vector for this process could be provision of monetary funds from the central, carbon tax collection reserve.

Using the Turkish energy mix reported in Table 6 and the production cost price of solar water heaters given in Table 10 the tax levy that would result in replacement of fossil fuels with thermal applications of solar energy may be worked out. This figure comes out as 0.93 US cents/kWh of energy yield and this translates to a penalty of 16.1 US cents/kg C emitted (161 USD/tonne C). The above analysis is based on an average national solar energy income of 4.3 kWh/m^2 day for Turkey (see Table 9) and it has been assumed the revenue raised from the tax levy would be equal to the cost of manufacturing the type of solar water heater that is under discussion. It is interesting to note that the present figure of 161 USD/tonne is comparable to that proposed by Wolf [15], i.e. 170 USD/tonne C.

3.1.10. Co-operative housing associations

This factor may become important for introduction of solar water heating within the domestic sector. It is proposed that with the view to reduce capital cost associated with the construction of the above heaters, the activity may be based on a co-operative associations' model. As part of the present study a survey of 100 households was carried out within the Kadikoy area of Istanbul. That survey indicated that around 70% households would be willing to participate in such a venture. This may be explained by the rising energy prices that are currently sweeping across Europe.

3.2. Barriers

3.2.1. Rising bank interest rates

Turkey established a customs union with the EU in 1995 thus significantly increasing the volume of trade with EU member states. The EU is now Turkey's biggest trading partner,

Table 10
Life cycle assessment of solar water heater (110 and 45 mm depth)

Entity	Quantity (kg)		Embodied energy (MJ)		Carbon released (kg)		Monetary Costs (USD)	
	110	45	110	45	110	45	110	45
Aluminium	9.5	8.5	1373	1226	24	21.4	37	33
Glass	11	11	340	340	6.7	6.7	5	5
Mono-block insulation	2	2	40	40	1.75	1.75	2	2
Rubber	0.1	0.1	15	15	0.28	0.28	1.5	1.5
Galvanized steel	3	3	75	75	0.8	0.8	6	6
Brass	2	2	98	98	1.8	1.8	3	3
General steel	2	2	70	70	1.28	1.28	0.75	0.75
Production			10	10	0.2	0.2	66.3	61.5
Total			2026	1879	36.7	34.1	122	113
Annual saving			881	809	45.8	42.1	22	20.2
Pay back (years)			2.3	2.3	0.8	0.8	5.5	5.6

particularly in agricultural and steel products. While the proportion of Turkey's population working in agriculture is still disproportionally high, there is currently a transition to service economy. Turkey has also recently liberalized its banking laws and removed state controls from markets including electricity, telecommunications, sugar, tobacco, and petroleum. As a result the banks have introduced very high interest rates which are in the region of 20–24% and this factor is detrimental to investment in new technology.

3.2.2. EU merger related issues and the current political situation

In view of the potential economic windfall as a result of joining the EU, Turkey has met every legal criterion that has been demanded by its prosperous neighbours. The country has implemented a host of political reforms, including abolishing the death penalty, allowing greater freedom of speech, and increasing rights for its Kurdish minority. Turkey supports EU foreign policy and has troops stationed in Bosnia as part of an EU military mission there. In May 2006, Ankara passed a new criminal code that established a more progressive national legal system. Over the course of the accession talks Turkey will be required to adopt EU laws that will cover everything from foreign and economic policy to environmental protection. One issue that is already affecting Turkish industry is the increase in labour costs within all manufacturing sectors as has been pointed out above.

3.2.3. Increase in the cost of metals

The price of aluminium is facing an upward trend in the international market. It can also be seen from Fig. 4, that the price of aluminium in the international market has experienced sharp fluctuations in recent years [16]. Although, as may be seen from the latter figure, of late the price of aluminium seems to have settled, this factor may be of significance in future exploitation of solar water heating within Turkey. As shall be shown later on in this article, aluminium provides an excellent performance when used in the construction of solar water heaters.

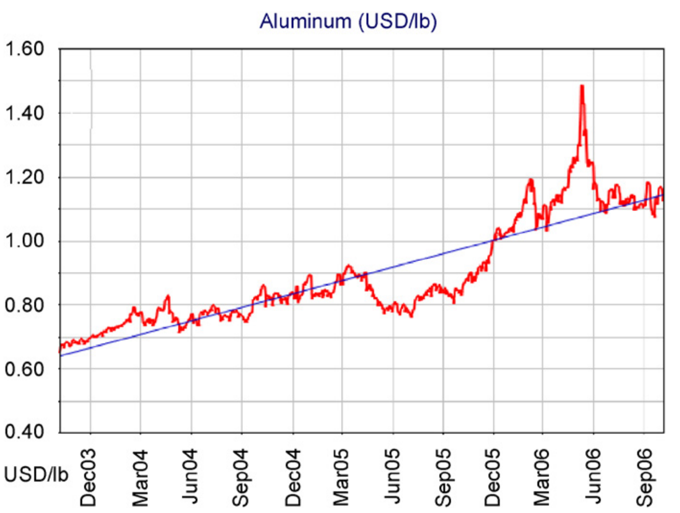

Fig. 4. Trend in aluminium price over the last 3 years [16].

4. Proposed design and economics for solar water heaters

4.1. Water consumption profile

Ozturk has undertaken a systematic study of the energy requirements of textile mills in Turkey [2]. For the sake of present study a further, more recent survey of textile mills was undertaken. It was found that an average mill produces cotton loom (white and dyed), viscose and synthetic, polyester material. An average-sized mill employs between 150–180 people, with an annual turnover of 7–8 USD million and produces 7–8 thousand tonnes of cloth fabric. The typical hot water usage within a medium-sized textile mill is 500 tonnes raised to 40 °C (for washing and cleaning of cotton loom), 300 tonnes raised to 60 °C (for cotton dyeing and production of viscose) and 200 tonnes raised to 80 °C (for production of synthetic, polyester material). Thus the total hot water consumption is 1000 tonnes/day. The intermediate process of raising water to 60 °C requires very close control of temperature increase, from the sourced ground water that is available at an average temperature of 12–18 °C depending upon the season. The desired rate of 1 °C/min increase in the latter process would be difficult to achieve by means of solar water heating plant. Hence in the present study a hot water requirement of 500 and 200 tonnes respectively raised to 40 and 80 °C is considered. The demand is almost continuous and the mill runs on a 16-h shift, thus requiring 31,250 and 12,500 kg/h of hot water at respective temperatures of 40 and 80 °C. It is also proposed that solar hot water is used up between 8–16 h (solar time), thus obviating the need for large storage. In the proposed scheme, therefore, under ideal conditions roughly half of the hot water requirements would be met by solar means.

It may be of interest to note that presently the textile mills raise low-pressure steam at 180 °C, which is then used in turn to produce hot water. Typically, 12.5 kg of steam/m^3 of natural gas burnt, is produced, or alternatively by burning 1 kg of coal.

4.2. The proposed solar water heater and its local manufacturing cost

The present authors have been engaged in the design, construction and experimentation of integrated-collector storage (ICS) solar water heaters for the past 25 years [17–20]. An older name for this heater is also ‘bread-box heater’, owing to its rectangular shape. An alternate name that has also been used within literature is built-in-storage heater. The present authors have built such heaters, attuned to the climate and needs of the respective regions in Africa, Asia and Europe. After several years of relative obscurity (the basic design was quite popular in the early 1900s!), built-in-storage heaters are back in vogue, albeit with enhanced design features, e.g. Muneer at al. [19] and Henderson et al. [21] who devised fins that are welded perpendicular to the absorber plate and thus rapidly dissipate heat to water, Cruz et al. [22] who employed a trapezoidal cross-section for storing a larger mass of heated water at the top end, and Liu et al. [23] who incorporated a heat-exchanger based system. The three research teams, i.e. Muneer at al. [19], Henderson et al. [21] and Cruz et al. [22] have reported average efficiencies of over 50% for producing water up to a temperature of 75 °C.

Detailed design features and the merits of using vertical fins were provided by Muneer et al [19]. In Pakistan for example, for the domestic sector a tank depth of 80 mm results in provision of 80 litre of hot water/m^2 absorber area. However, in view of hourly hot water demand within the textile industry it is herein proposed that a water tank depth of 40 mm is

used for rapid hourly temperature lift from the sourced ground water temperature of 12–18 °C.

A survey of material prices within the local market was undertaken. It was found that the cost of Grade 1050 aluminium was 3.6 USD/kg. The cost of 50-mm mono-block insulation was 30 USD/m^2. The total cost involved in producing solar water heater has been calculated in USD to be 122 and 113 for respective depths of 110 and 45 mm. Table 10 provides a detailed breakdown of the total cost.

4.3. Energy delivery performance of proposed solar water heaters

In previously reported work [19,20] the present authors have presented the measured, in-situ thermal performance of ICS solar water heaters that they operated for a period of 1 year near Lahore, Pakistan. That work was also carried out at the behest of a local textile mill. The latter heaters, one a plain heater and the other one that used innovative longitudinal fins were constructed from steel. A detailed monetary, environmental and energetic payback analysis was also presented. Furthermore, on the strength of the latter study an extension of experimental work was carried out wherein aluminium-based heaters (plain and finned) were constructed and operated over a period of 3 months. The results of the above studies regarding the ICS heater efficiencies may be summarized as follows: for 20° collector tilt of the absorber plate from the horizontal the steel, un-finned heater gave an overall efficiency of 47%. Likewise, the steel, finned; aluminium, un-finned and aluminium, finned heaters performed at respective efficiencies of 55%, 61% and 64%.

Note that the introduction of fins that are attached to the plain absorber plate not only improves the thermal efficiency of the heater but also adds to the structural stability of the construction—fins joined to the top and bottom heater plates provide additional strength against hydrostatic forces and can help overcome the bulging problems that usually arise in such designs. Note that the fin attempts to enhance the heat transfer from the absorber plate to the deeper layers of water. Furthermore, within the plain-absorber heater the fact that heat is being transferred from a heated plate at the top to a cooler body of water residing underneath is an inefficient convection process. On the other hand, the vertically placed fin has a better opportunity to transfer heat.

A simulation study of aluminium-finned heater was then undertaken. The hourly energy exchange simulation was closely based on the work of Cruz et al. [22,24] and incorporates the thermal model that is shown in Fig. 5. Standard regression models for heat transfer from an inclined absorber plate and vertical fins to water are available in literature, e.g. [27]. The monthly averaged solar radiation and maximum/minimum ambient temperature data that was available for Antalya, Turkey was converted to hourly values using the respective works of Collares-Pereira and Rabl [25] and ASHRAE [26]. Note that Muneer [27] has provided FORTRAN-based routines for the above daily-to-hourly conversions.

The results of the above-mentioned simulation study provided the following results. For textile industry in southern Turkey that requires heated water at 40 °C a built-in-storage depth of 110 mm that will produce 110 litre of hot water/m^2 collector area yields an annual energy of 705 kWh. The solar fraction in this case is 60.2%. Likewise, for a 80 °C heated water demand a storage depth of 45 mm would produce 45 litres of hot water/m^2 collector area and an annual energy yield of 647 kWh would be achieved. The solar fraction in this case is 51.6%.

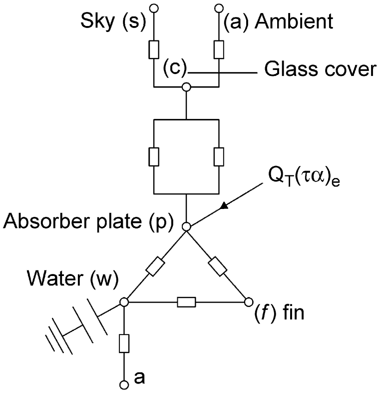

Fig. 5. Thermal circuit for solar water heater.

As an addendum to this study it may also be noted that for domestic applications the solar fraction in this case would be dependant on the water use profile and would be of the order of 55–60%.

4.4. Economic and life-cycle assessment (LCA)

A detailed economical analysis has been undertaken for the above-mentioned solar water heaters the results of which are briefly presented here. Based on the average daily energy output, the annual energy yield has been calculated to be equal to 705 and 647 kWh, respectively, for heaters at 110 and 45 mm depth. Compared against conventional energy means, an economic payback for the heater has been calculated to be equal to 5.5 and 5.6 years, respectively.

A LCA study involving an account of the embodied energy and environmental impacts associated with the materials involved in the construction of the heater and the production process has been conducted. Materials crucial to this study include aluminium, glass, mono-block insulation, rubber, galvanized steel, brass and general steel that have respective embodied energy values of 145, 31, 148, 20, 25, 49 and 35 MJ/kg [19,20]. The amount of carbon released in producing one kg of the involved respective materials is 2.53, 0.61, 0.88, 2.75, 0.68, 0.91 and 0.61 kg. The total embodied energy values for the heaters of 110 and 45 mm depth have been calculated to be 2026 and 1879 MJ, respectively. Taking into account the annual energy produced by heaters, the embodied energy payback period for both of the heater has been calculated to be equal to 2.3 years. The carbon pay back period for the heaters has been estimated to be 0.8 and 0.8 years, respectively, as shown in Table 10.

5. Conclusions

After several years of relative obscurity, built-in-storage heaters are back in vogue, albeit with enhanced design features, e.g. fins that are welded perpendicular to the absorber plate which rapidly dissipate heat to water. A simulation study of aluminium-finned heater was then undertaken. The hourly energy exchange simulation incorporates the thermal model that is shown in Fig. 5. The results of the above-mentioned simulation study provided the

following results. For textile industry in southern Turkey that requires heated water at 40 °C a built-in-storage depth of 110 mm that will produce 110 litres of hot water/m^2 collector area yields an annual energy of 705 kWh. The solar fraction in this case is 60.2%. Likewise, for an 80 °C heated water demand a storage depth of 45 mm would produce 45 litres of hot water/m^2 collector area and an annual energy yield of 647 kWh would be achieved. The solar fraction in this case is 51.6%. The economic payback period for heaters with 110 and 45 mm depths has been calculated to be equal to 5.5 and 5.6 years, respectively. Results of a life cycle assessment show that the embodied energy and carbon payback period for both of the heaters is respectively 2.3 and 0.8 years.

Using the Turkish energy mix reported in Table 6 and the production cost price of solar water heaters given in Table 10 the tax levy that would result in replacement of fossil fuels with thermal applications of solar energy was worked out. This figure comes out as 0.93 US cents/kWh of energy yield and this translates to a penalty of 16.1 US cents/kg C emitted (161 USD/tonne C).

Acknowledgements

The authors are grateful to Napier, Yildiz & Pamukkale Universities for supporting this project. The help extended by Boler textile industries group and Istanbul home energy surveyors is also acknowledged. T Muneer would like to thank the Carnegie Trust (Scotland) for providing travel research grant that enabled him to visit the textile industry network within Turkey.

References

[1] The world guidebook 2003/2004. Oxford: New Internationalist Publications; 2004.
[2] Turkish economy in 2005, report on insurance and private pension activities in Turkey, 〈http://www.hazine.gov.tr/SDK2005/doc-e/reportecon.pdf〉, 2005.
[3] CEPS. The textiles and clothing industry in an enlarged community and the outlook in the candidate states, Part 1 Supplement: Turkey, 〈http://ec.europa.eu/enterprise/textile/documents/tc_study_jan_2005_turkey.pdf〉, 2005.
[4] State Planning Organization. Basic economic indicators, 〈http://ekutup.dpt.gov.tr/program/2006.pdf〉, 2006 [in Turkish].
[5] Turkish Ministry of Energy. Turkish energy economics and future of petroleum. 2006 [in Turkish].
[6] DEIK, Turkish–US Business Councile. Economic partnership between Turkey and the USA, recent dynamics, 〈http://www.turkey-now.org/db/docs//abd-tr%20ekonomikrapor-ing2005.pdf〉, 2006.
[7] Kosgeb. Turkey sectorial report for fashion-net project, 〈http://www.kosgeb.gov.tr〉, 2006.
[8] Turkish Ministry of Energy, 〈www.enerji.gov.tr〉 2006.
[9] Aksoy B. Estimated monthly average global radiation for Turkey and its comparison with observations. Renew Energy 1997;10(4):625–33.
[10] Comission of European Communities. European solar radiation atlas. Paris: Ecole des Mines; 2002.
[11] Epp B, editor. Sun Wind Energy 2006;1.
[12] 〈http://www.euractiv.com/en/energy/geopolitics-eu-energy-supply/article-142665〉.
[13] The EU directive on electricity from renewable energy sources. Directive 2001/77/EC, 2001.
[14] Brookings papers on economic activity (2005), a robust strategy for sustainable energy. Available at 〈www.earthinstitute.columbia.edu〉, 2, 2005.
[15] Wolf M. Taxation can give the earth a chance. Financ Times 2006;19:15.
[16] 〈http://www.infomine.com/investment/metalschart.asp?c = aluminum&u = mt&submit1 = Display + Chart&x = usd&r = 3y〉.
[17] Muneer T, Hawas M. Experimental study of the thermosyphon and built-in-storage type solar water heaters. In: Proceedings of the energex '84 conference. Regina, Canada, 1984, p. 497–500 [ISBN: 0-08-025407-1].

[18] Muneer T. Effect of design parameters on performance of built-in-storage solar water heaters. Energy Convers Manage 1985;25:277–81.
[19] Muneer T, Maubleu S, Asif M. Prospects of solar water heating for textile industry in Pakistan. Renew Sustain Energy Rev 2006;10:1–23.
[20] Asif M, Muneer T. Life cycle assessment of built-in-storage solar water heaters in Pakistan. Build Ser Eng Res Technol 2006;27:1.
[21] Henderson D, Junaidi H, Muneer T, Grassie T, Currie J. Experimental and CFD investigation of an ICSSWH at various inclinations. Renew Sustain Energy Rev 2007;11(6):1087–116.
[22] Cruz JMS, Hammond GP, Reis AJPS. Buoyancy-driven convective heat exchange in a trapezoidal-shaped solar collector/thermal store. In: Proceedings of the fifth ASME/JSME joint thermal engineering conference. San Diego, CA, March 15–19, 1999.
[23] Liu W, Davidson JH, Kulacki FA. Thermal characterization of prototypical integral collector storage systems with immersed heat exchangers. J Sol Energy Eng 2005;127.
[24] Cruz JMS, Hammond GP, Reis AJPS. Thernal performance of a trapezoidal-shaped solar collector/energy store. Appl Energy 2002;73:195–212.
[25] Collares-Pereira M, Rabl A. The average distribution of solar radiation—correlation between diffuse and hemispherical and between daily and hourly insolation values. Sol Energy 1979;22:155.
[26] ASHRAE handbook of fundamentals. Atlanta, USA: American Society of Heating Refrigeration and Air-conditioning Engineers; 1993.
[27] Muneer T. Solar radiation and daylight models. Oxford: Elsevier; 2004.